

# GEOMORPHIC PROVINCES AND SECTIONS OF THE NEW YORK BIGHT WATERSHED

## **1. Atlantic Coastal Plain Province**

### Sections

*Embayed Section*

*New Jersey Outer Coastal Plain*

*New Jersey Inner Coastal Plain*

*Long Island Coastal Lowlands*

*Barrier Beach System*

## **2. Piedmont Province**

### Sections

*Piedmont Lowlands (Northern Triassic Lowlands)*

## **3. New England Province**

### Sections

*New England Uplands*

*New York/New Jersey Highlands (Reading Prong)*

*Manhattan Hills (Manhattan Prong)*

*Staten Island Serpentine*

*Taconic Mountains*

*Taconic Highlands*

*Rensselaer Plateau*

*Stissing Mountain*

## **4. Ridge and Valley Province**

### Sections

*Great Valley*

*Kittatinny Valley*

*Wallkill Valley*

*Hudson Valley*

*Shawangunk/Kittatinny Ridge*

## **5. Appalachian Plateaus Province**

### Sections

*Glaciated Allegheny Plateau*

*Catskill Mountains*

*Heidelberg Mountains*

## **PHYSIOGRAPHIC SETTING**

### **Regional Geomorphology**

The inextricable and vital linkage between living organisms and their physical environment, or habitat, is generally well known to scientists and the public. In this report we have looked at species populations and their habitats from a broad regional perspective, focusing on large-scale physical landscape features as the basic habitat units for protection and conservation. The

following general information is provided to help understand the regional physical classification units that were used as the basis for grouping and delineating regional habitat complexes.

*Geomorphology*, or physiography, is a distinct branch of geology that deals with the nature and origin of landforms, the topographic features such as hills, plains, glacial terraces, ridges, or valleys that occur on the earth's surface. *Regional geomorphology* deals with the geology and associated landforms over a large regional landscape, with an emphasis on classifying and describing uniform areas of topography, relief, geology, altitude, and landform patterns. These regions are generally referred to as *GEOMORPHIC* or *physiographic provinces* or *regions* and have been classified and described in various texts for the northeastern region and for the United States as a whole. The larger regional provinces are often further subdivided into subunits or *sections*, depending on the classification system used.

A rich and varied regional physical landscape, containing a number of distinctive regional GEOMORPHIC provinces and sections, is evident within the New York Bight watershed. This GEOMORPHIC variety is the result of several concurrent and successional events: the combination of complex bedrock and surficial geology and recent glacial history in the northern half of the region; historical mountain-building and regional land uplifting forces; and the dynamic processes of erosion, sedimentation, and chemical and physical weathering acting differentially on rock types of various hardnesses. Such extraordinary physiographic diversity and geological complexity, along with climate and historical events, have contributed directly to the region's remarkable biological diversity and the current distribution patterns of its fauna and flora. It is clear that the high-elevation, carbonate-rich peaks and sedimentary rocks of the Catskills support a biota entirely different from that of the unconsolidated and acidic sands of the New Jersey pine barrens along the low-lying Atlantic coast, just as both of these differ strongly from the erosion-resistant traprock ridges of the Palisades and the crystalline metamorphic rocks of the New York -New Jersey Highlands.

One of the most interesting and significant factors to shape the modern landscape of a substantial portion of the New York Bight watershed, and, indeed, much of North America, has been the work of glaciers and the continental ice sheet during the most recent glacial period, the *Pleistocene Epoch*. Although the Pleistocene began more than a million years ago and was characterized by a series of at least four major glacial advances (glacial stages) and retreats (interglacial stages), it is the last glacial event, the *Wisconsin glacial stage*, that has had the most profound influence on the landscape of the northern section of this region. The Wisconsin ice sheet or glacier, which began between 70,000 and 100,000 years ago, was the most extensive in size and advanced the furthest south of all the Pleistocene glaciers, and only retreated from this region between 10,000 and 15,000 years ago. It has resulted in the two sections of the New York Bight watershed, the northern glaciated portion and the southern unglaciated portion, standing in marked contrast to each other, and has added a measurable and observable distinctiveness to the landscape and biota of each area and to the watershed as a whole.

During the height of glaciation, the northern section of the watershed was covered by an ice sheet up to 1.6 kilometers (1.0 mile) thick, though its thickness was considerably less along its margins and eastern portions. Over the entire glaciated portion of the watershed, a layer of unsorted and unconsolidated glacial debris, *glacial till*, ranging from clay particles to huge boulders, was directly deposited on the landscape by the advancing glacier. Following the retreat of the ice sheet, the post-Pleistocene landscape, with its rock-strewn surface and polished bedrock surfaces, was devoid of higher plants and animals, leaving a clean slate for the migration and colonization of modern plant and animal communities in the region.

The former edge of the Wisconsin ice sheet is conspicuously marked by a distinctive, ridge-like *terminal* or *end moraine* running approximately east-west through the center of the watershed study area, and effectively delineating the line between the glaciated and unglaciated sections. The moraine is composed of rock debris from the bedrock of New England, New York, and northern New Jersey that was eroded, ground up, transported southward, and deposited at the edge of the ice sheet in those areas where it remained in place for a relatively long while, long enough for rock debris to accumulate. The terminal moraine averages 1.6 to 3.2 kilometers (1 to 2 miles) in width along most of its length in the watershed. It contains numerous boulders and appears more like a range of low hummocky knolls and hills, intermediate valleys, and kettle hole basins than an unbroken ridgeline. On Long Island, two distinct and roughly parallel end moraines make up the core of the island: the *Ronkonkoma Moraine* and the *Harbor Hills Moraine*. At the eastern end of the island these two moraines are quite distinct from each other and are separated by an intermorainal area 19 to 22 kilometers (12 to 14 miles) wide, which includes the Peconic Bays. Toward the western end of the island, about 32 kilometers (20 miles) east of New York City, the two moraines intersect and are united to form a single end moraine, which continues westward across Staten Island and into Perth Amboy, New Jersey, and from there northwestward and westward across northern New Jersey.

As the Wisconsin glacial front retreated in response to a warming global climate, the glacier left many smaller recessional moraines and other distinctive glacial landforms, e.g., kames, kettles, eskers, and drumlins, across the landscape north of the terminal moraine. Meltwater from the melting ice sheet, in association with moraines, created several large glacial lakes in the watershed; the most prominent are Glacial Lake Passaic, Glacial Lake Hackensack, Glacial Lake Hudson, and Glacial Lake Albany. These lakes lasted for thousands of years and their remnants are visible today in the form of lakeshore sand and dune deposits and basins of deep marsh peats and lake sediments. In addition to these large lakes, there are many smaller lakes and wetlands north of the terminal moraine that were also formed from the blockages of preglacial streams by glacial deposits or excavated by the ice into the bedrock. All of the 60 natural lakes that occur in New Jersey, for example, occur north of the moraine.

The weight of the Wisconsin ice sheet caused the crust of the continent to sag, depressing the land east and north of New York City and elevating the coastline south of the city. During the maximum period and extent of glaciation during the Wisconsin stage, much of the surface water was locked up as frozen ice in the ice sheet and sea level was some 107 to 122 meters (350 to 400 feet) lower than at present, exposing hundred of miles of the continental shelf in the New York Bight. With the warming of the climate and the retreat of the ice sheet, the depressed land rebounded and sea level rose to its present level and continues to rise.

### **Geomorphic or Physiographic Provinces**

It is the intricate pattern and diversity of physical landscape features -- geology, landforms, topography, altitude, relief, geological and glacial history, and hydrology -- and the associated biological communities and species populations in the New York Bight watershed that have served as the basis and focal point of this report's approach to identifying and delineating regionally significant habitat complexes. The habitat complexes described in this report represent units that are closely integrated with natural landscape features rather than with political boundaries, property lines, and/or local species occurrences. In this project, the geomorphic region has served as the primary hierarchical landscape unit within which the various individual habitat complexes have been grouped and described. These geomorphic regions (provinces) are

summarized here and shown in Figure 3.

The states of New York and New Jersey have each developed similar statewide physiographic classifications and units, based on broader regional classifications, and their units were able to be joined, integrated, and described for the purposes of this report. In its report on ecological zones of southern and western New York, the New York State Department of Environmental Conservation recognizes a number of zones and subzones that are roughly equivalent to geomorphic or physiographic regions described in existing earlier classifications of the physiography and physical geology of the state. Similarly, the state of New Jersey recognizes five physiographic regions in the state, all of which along its northern border are contiguous with similar regions or zones in adjoining New York State. Those physiographic regions occurring in the New York Bight study area, arranged from those closest to the coast to those furthest inland and up the watershed, are listed and briefly described in this section.

## **1. Atlantic Coastal Plain Province**

Embayed Section

New Jersey Outer Coastal Plain

New Jersey Inner Coastal Plain

Long Island Coastal Lowlands

Barrier Beach System

The Coastal Plain of the eastern United States is an extensive seaward-sloping plain of marine sands, clays, gravels, and marls that stretches 3,540 kilometers (2,200 miles) along the coast from Cape Cod, Massachusetts, to the Mexican border, and continues another 1,600 kilometers (1,000 miles) southward into Mexico. That portion of the Coastal Plain from the southern tip of Florida along the east coast north to Cape Cod, is referred to as the Atlantic Coastal Plain Province and includes the coastline of the New York Bight watershed. The Coastal Plain in this region is further subdivided into several smaller geomorphic units, called sections, based on differences in geology and topography. The *Embayed Section*, from North Carolina to Cape Cod, includes the New York Bight and is the area of most recent submergence as a result of the weight of the last ice sheet and subsequent postglacial rebound, or rise, of the land. This section is characterized by broad peninsular tracts, drowned river estuaries, and a series of coastal terraces that extend back almost to the Fall Line, the boundary between the Piedmont and the Coastal Plain (see Piedmont). The land surface of the Coastal Plain is often viewed together with the submerged offshore continental shelf as part of a continuous surface; when so considered, the combined Coastal Plain and adjacent shelf stretches from Florida to Newfoundland, though the area north of Cape Cod is wholly submerged. The width of the Coastal Plain proper, not including the Continental Shelf, is narrowest in the north in the vicinity of the New York Bight study area and widens out to a broad plain hundreds of kilometers wide in the southeastern United States.

The Coastal Plain Province of the Bight includes about 60% of the total land area of the state of New Jersey, almost the entire southeastern part of the state south of lower New York Bay and Raritan Bay, and extends northeastward into New York State to include all of Long Island. This region is characterized by low topographic relief and occupies nearly the entire coastal section of the Bight watershed, except for the immediate urban core, which is included within the Piedmont and New England Upland Provinces. Elevations range from sea level to nearly 120 meters (ca. 400 feet) above, with most of the area being less than 30 meters (ca. 100 feet) in elevation. Climatically, this area is strongly influenced by the ocean and is thus cooler in summer and

warmer in winter than are the more interior areas of the Bight watershed.

In New Jersey, the Coastal Plain is composed of an *Inner* and *Outer Coastal Plain* and, although they are not greatly different geologically, they are quite distinct geographically. The *Inner Coastal Plain* lies inland to the west and northwest of the much larger *Outer Coastal Plain*. Within the Bight watershed, the Inner Coastal Plain drains north into Raritan Bay, while the Outer Coastal Plain, lying adjacent to the Atlantic Ocean, drains directly into the New York Bight or into the backbarrier coastal lagoons along the Jersey shore. Most of the materials on both the Inner and Outer Coastal Plains in New Jersey are marine-deposited sedimentary sands, gravels, and clays overlain with later deposits made in interglacial Pleistocene time, but the Inner Coastal Plain has a larger proportion of clay in its soil than does the Outer Plain, which is sandier and also the site of an important aquifer in the region. Soil differences between the two Coastal Plain segments are significant. Because of its more fertile soils, the Inner Plain has long been distinguished as an important agricultural area that gives the Garden State its name, while the Outer Plain, with its sandier, excessively well-drained, and lower fertility soils, is dominated by the equally renowned New Jersey pine barrens, now known as the Pinelands. Although the Pinelands are typically viewed as being very dry, in many places the water table is quite close to the surface, giving rise to extensive wetlands. The Inner Coastal Plain, whose sedimentary deposits were laid down during the Cretaceous period, is separated from the Outer Coastal Plain, of Tertiary age, by a belt of low hills called *cuestas*. These *cuestas* are capped by a formation of cemented sands and gravels; some of the larger hills are nearly 120 meters (400 feet) high, including Beacon Hill at 114 meters (373 feet) and Arney's Mount at 70 meters (230 feet) above sea level. This feature is not found on Coastal Plain sections to the south. Altogether, the Coastal Plain of New Jersey may be viewed as a plain that rises gradually from sea level on the east, west, and south to elevations as high as nearly 120 meters (400 feet) where the Inner and Outer Coastal Plains join at the northeast-southwest trending *cuestas*. The major rivers draining into the New York Bight from this relatively flat, low-lying region are those that originate in the Pinelands, and include the Mullica, Great Egg Harbor, Tuckahoe, Wading, Toms, Forked, Metedeconk, and Manasquan Rivers. These rivers of the Pinelands are slow-flowing, rich in humates that impart a brown tea color to the water, low in nutrients, and acidic; many are tidal for significant portions of their length.

The Coastal Plain deposits of New Jersey continue northeastward, dipping downwards below the surface, to Long Island, and lie buried well beneath the land surface on Long Island. Unlike the New Jersey section of the Coastal Plain, the surface of the *Long Island lowlands* is strongly modified and covered by glacial deposits from the most recent (Wisconsin stage) glaciation, and consists of moraine deposits, glacial drift, and outwash materials. The general topography of Long Island is that of a plain that slopes southward from an elevation of roughly 60 meters (200 feet) or less along the middle and northern portions of the island, at the crests of the two terminal moraines, and grades gradually into extensive deposits of outwash sands and gravels that reach sea level at the South Shore of Long Island. The gentle southward-sloping area of outwash materials emanating from the southernmost end moraine on Long Island is often referred to as an *outwash plain* and is similar to those found along the southeastern coast of New England on Cape Cod and the outer islands of Martha's Vineyard, Block Island, and Nantucket. The valleys of the South Shore outwash plain, of uncertain origin, are characteristically short, shallow, and indefinite depressions that have been called dry rivers or furrows. Streams and rivers along the South Shore are also very narrow and short in length; only two major rivers occur along Long Island's South Shore, the Carmans River and the Connetquot River.

Long Island has two prominent end moraines that traverse the island almost from one end to the other, including both eastern forks. The southernmost and older of the two moraines, the Ronkonkoma Moraine, makes up the central and south fork sections of Long Island, and includes the Montauk Peninsula. South of the Ronkonkoma Moraine is an extensive *outwash plain* of water-sorted sands and gravels deposited by meltwaters at the edge of the ice; intermorainal outwash deposits also occur between the two moraines. The Harbor Hills Moraine makes up the north shore and north fork of the island, including Orient Point, Plum Island, and Fishers Island. It is the younger of the two moraines and is sometimes referred to as a *recessional* moraine, marking where the glacier retreated from its position at the Ronkonkoma Moraine and remained in place for an extended period of time. Another speculation is that the Harbor Hills Moraine represents a glacial advance that was preceded by an interglacial stage. Near the western end of the island these two moraines are united, becoming distinct about 32 kilometers (20 miles) east of New York City and separating at the east end where they are 19 to 22 kilometers (12 to 14 miles) apart. The maximum heights of the moraines are 119 meters (391 feet) in the Harbor Hill moraine and 125 meters (410 feet) in the Ronkonkoma moraine; both elevations occur west of the middle section of the island. The New York Bight watershed boundary along the southern portion of Long Island follows the approximate position and crest of the Ronkonkoma Moraine in the eastern half of the island, and along the ridge of the united moraines in the western half. Along both the Long Island and New Jersey Atlantic coasts at the very edge of the Atlantic Ocean, there is an extensive, narrow strip of elongated *barrier beaches*, *baymouth barriers*, *barrier spits*, and *barrier islands*, often broken by tidal inlets, that is typically separated from the mainland by a backbarrier lagoon (saltwater bay), a marsh system, or a combination of the two. At the eastern end of Long Island, the erosion of glacial morainal and till deposits at Montauk Point serves as the headland source of the beach sands that comprise the relatively recent (4,000 years) barrier island system and offshore bars paralleling the shore for nearly three-fourths the length of the island. Eroded glacial sediments are carried westward from Montauk Point in the longshore, or littoral, current and deposited by wave action on the barrier beaches and offshore bars. In addition to the westward growth and movement of the beaches on Long Island, there is also a landward migration of this system in response to diminishing sediment supply and relative sea level rise; the latter is estimated at around 15 to 40 centimeters (6 to 16 inches) per century in this region and results in a shoreline retreat of 1 to 3 meters (3 to 9 feet) per year in some places. In contrast to the erosion of glacial materials on Long Island, in New Jersey the coastal plain deposits of the Atlantic Highlands serve as the primary headland source of sand for the beaches along the Atlantic coast of southern New Jersey. Eroded materials from the region of the Highlands are swept in the littoral current northward to form the Sandy Hook peninsula, and southward towards Cape May to form the greater part of the barrier beach system that is commonly known as the Jersey Shore. As on Long Island, the New Jersey beaches are also migrating landward in response to a global rise in sea level.

The barrier beach system of the Jersey Shore south of Sandy Hook may be viewed as being composed of three sub-areas, from north to south: the mainland-fronting beach area from the Atlantic Highlands south to Bay Head; the barrier beach segment from Bay Head to Ocean City, where there is an extensive open water lagoon system in back of the barrier beaches, with few inlets; and the barrier beach section from Ocean City to Cape May where inlets are more frequent, the barrier beach segments shorter, and the backbarrier lagoon is being filled in by sediments and dominated by marshes. A fourth sub-area, between Brigantine/Little Egg Inlet and Ocean City, is transitional between water-dominated and marsh-dominated backbarrier systems.

A similar pattern of barrier beach segments occurs along the south shore of Long Island, running east to west: Montauk to Southampton (mainland-fronting beaches); Southampton to Fire Island Inlet (large open water lagoons or bays, with few inlets); and from Fire Island Inlet to Coney Island (extensive backbarrier marshes, more frequent inlets, shorter beach segments). The barrier beach systems along the Atlantic Ocean shoreline of Long Island and New Jersey often contain substantial dune ridges that parallel the shoreline as well as extensive sand flats, interdunal swales, and tidal marshes in back of the dunes. Barrier beach systems as a rule are highly dynamic, constantly changing their shapes, beach widths, and landforms, sometimes radically, on a daily, seasonal, or annual basis, but especially in response to extreme storm events such as hurricanes and nor'easters, both of which are common in this region. These storm events do considerable damage to man-made structures, but are an important part of the natural coastal process and are quite significant in maintaining a diversity of natural biological communities on the beaches and in the lagoons.

## **2. Piedmont Province**

### **Piedmont Lowlands (Northern Triassic Lowlands)**

The Piedmont Province of the eastern United States extends from the Hudson River at the north to Alabama at the south and ranges from 16 kilometers (10 miles) wide at its narrowest, in the Bight region, to about 200 kilometers (125 miles) at its widest, near the Virginia-North Carolina border. The province as a whole may be viewed as the nonmountainous portion of the older Appalachian Mountains whose flat plateau surface is the product of erosion and degradation. Along most of its length, the Piedmont is situated between the Appalachian Mountains to the west and the Coastal Plain to the east and slopes from the mountains towards the coast. In the southern part of this Province the boundary between the Piedmont and the Coastal Plain is called the Fall Line or Fall Zone, so named because of the prevalence of rapids and falls at the topographic juncture of the more resistant and higher elevation rocks of the Piedmont and the more erodible and lower-lying rocks and sediments of the Coastal Plain. The Piedmont Province is divided into Upland and Lowlands sections; in the northern portion of the Piedmont only the Lowlands section is present, dominated by Triassic rocks. The Lowlands are often further subdivided into Northern and Southern Triassic Lowlands.

In the New York Bight watershed, the *Piedmont Lowlands* section, also known as the Newark Basin or Triassic Lowlands, represents the northern extension of an almost continuous formation of reddish shales, mudstones, and sandstones that stretches nearly 1,600 kilometers (1,000 miles) from the Hudson River near the border of New Jersey and New York near Nyack, New York, southward through Maryland into Virginia. There are also scattered basins of these same rocks in New England and the Canadian Maritime Provinces, but these are not considered part of the Piedmont. In the Northeast, including the New York Bight watershed, the *Northern Triassic Lowlands* section extends from the Palisades of the Hudson River in New York State southward to the Schuylkill River in Pennsylvania.

The Piedmont of the New York Bight watershed is a relatively low-lying area of broad valleys and low hills that slopes gently in a southeastward direction from its highest elevations of about 122 meters (400 feet) above sea level in northeastern New Jersey to sea level at Newark Bay. It lies between the Highlands, or Reading Prong, to the northwest and the Coastal Plain to the southeast. The Piedmont's fertile, arable soils and flat, easily developed terrain have resulted in dense urbanization over much of the northeastern portion of this area and extensive agricultural activity in its southwestern portion, with only small fragments of natural habitat remaining. Its

gently rolling surface of readily erodible sedimentary sandstones and shales and deep reddish soils is interrupted by ridges of erosion-resistant igneous rock types, diabase and basalt, commonly called *traprock*. The most prominent traprock ridges in this physiographic region of the Bight are the three Watchung Mountain ranges of New Jersey, composed of extrusive basalts, and the Palisades Sill, composed of intrusive diabases; the latter extends more than 65 kilometers (40 miles) along the west bank of the Hudson River shorelines of northeastern New Jersey and adjacent southeastern New York, from west-central Staten Island north to Haverstraw, New York. The Palisades form a line of near-vertical cliffs along the Hudson with huge quantities of bouldery talus at their foot slopes, and range from near sea level at their bases along the river up to an average of 60 meters (200 feet) in elevation, with some maximum local elevations of between 150 and 210 meters (500 to 700 feet). Several miles west of the Palisades, standing out in bold relief in the Hackensack Meadowlands, are two small intrusive plugs, offshoots of the Palisades diabase, known as Snake Hill and Little Snake Hill. Still further west, maximum elevations on the three Watchung Mountain ridges are 106, 200 and 260 meters (350, 650, and 850 feet).

Another conspicuous landscape feature of the Northern Triassic Lowlands in the New York Bight watershed is the presence of large glacial lakes, such as Glacial Lake Hackensack and Glacial Lake Passaic in northeastern New Jersey; these were formed by the terminal moraine blocking the Passaic River and the deposition of other glacial materials blocking the Hackensack River. Two other lakes are connected with this system: Glacial Lake Hudson and Glacial Lake Flushing. Until glacial retreat allowed them to drain, these lakes endured for thousands of years before being filled with clay, sand, and gravel about 10,000 years ago and later with peat deposits from the marshes that grew in them. Today, the Passaic Meadows (Great Swamp/Great Piece Meadows/Troy Meadows) and the Hackensack Meadowlands occupy the lake basins of former Glacial Lakes Passaic and Hackensack, respectively.

### **3. New England Province**

New England Uplands

New York/New Jersey Highlands (Reading Prong)

Manhattan Hills (Manhattan Prong)

Taconic Mountains

Taconic Highlands

Rensselaer Plateau

Stissing Mountain

The *New England Province* is essentially a northward extension of the larger Appalachian Mountains or Highlands region. It is a plateau-like upland that rises gradually inland from the coast and is surmounted by mountain ranges or individual peaks. The principal mountain ranges are the Green, Taconic, and White, while the Berkshire Hills and Hoosac Mountains are southern extensions of the Green Mountains and are of lesser elevation. South and west of the Berkshires and Hoosac Mountains the physiographic distinction between them and the Taconic Mountains is difficult. The Province sends out two arms or prongs southeastward from New England that serve to connect it with the Appalachian provinces: the *Manhattan Prong*, which terminates at the tip of Manhattan Island, and the *Reading Prong*, which extends beyond the Hudson and Delaware Rivers to Reading, Pennsylvania. The region is one of complex mountains consisting primarily of metamorphic (schist, gneiss, slate, and marble) and igneous (largely granites) rocks of very ancient age that have been greatly compressed, uplifted, and deeply denuded, first by



fluvial agents and later by glaciers. With respect to the latter, the New England Province differs from the southern Appalachian region primarily in the fact that the entire region was glaciated, except for a portion in western New Jersey and Pennsylvania. Glaciation in this province, along with its more rugged topography, preponderance of crystalline rocks, and scarcity of calcareous rocks, has resulted in thinner, patchier, and generally acidic tills, which are also quite stony and bouldery. The geographic and physiographic complexity and diversity of the province has led to the recognition of five geomorphic sections: Taconic; Green Mountain; New England Upland; White Mountain; and Seaboard sections. Some authors add a sixth section: the Connecticut Valley Lowland.

The topography of the *New England Uplands section* is that of a maturely-dissected plateau with narrow valleys, and the entire area is greatly modified by glaciation. It is the most widespread of the geomorphic sections in the New England Province, extending from Canada through New England down to the Seaboard section and extending southwestward through New York and New Jersey as two narrow upland projections, the Reading and Manhattan prongs previously mentioned. Numerous hills and mountains rise above the general level of the upland; except in the presence of mountains, the horizon of the regional landscape is fairly level. Glaciation has resulted in the erosion and rounding off of the bedrock topography and numerous rock basin lakes. Glacial drift is thin, patchy, and stony, and ice-contact features such as kames, kame terraces, and eskers are abundant. The surface of the New England Uplands slopes southeast from maximum inland altitudes around 670 meters (2,200 feet), excluding the other mountainous sections of the province, to about 122 to 152 meters (400 to 500 feet) along its seaward edge at the narrow coastal Seaboard section, which goes down to sea level.

In the New York Bight watershed, the New England Uplands section is represented by a portion of the Taconic Mountains and its foothills, and by the Reading and Manhattan Prongs that extend southwestward from the New England states. Although geologists refer to the larger of these extensions as the Reading Prong, in this region it is more commonly known as the *New York - New Jersey Highlands*, and locally as the Hudson Highlands, the New Jersey Highlands, the Ramapo Mountains, or simply the Highlands. The Highlands are bounded on the southeast and on the northwest by the lowlands of the Piedmont and Great Valley provinces, respectively. The mountains and valleys that make up the Highlands are part of a relatively long, linear, and narrow regional geological feature that averages 16 to 32 kilometers (10 to 20 miles) in width, with a maximum width of 40 kilometers (25 miles), and extends in a southwest-northeast trending direction for nearly 225 kilometers (140 miles), from southeastern Pennsylvania near Reading, to southwestern Connecticut in the vicinity of Danbury, where it joins the Taconic Mountains and Housatonic Highlands of the New England Uplands plateau. The Hudson River cuts a deep gorge through the Highlands in New York in that stretch of the river between Peekskill on the south and Newburgh on the north.

The New York - New Jersey Highlands section is very complex geologically and is composed predominantly of erosion-resistant, contorted, and strongly metamorphosed crystalline rocks (gneisses and schists) and marble, mostly overlain with glacial till, with many areas of softer limestones and shales, especially in the valleys. This large group of rocks, the oldest in the Bight watershed, that makes up the Highlands is called the Highlands Complex. The northern section of the Highlands was glaciated during the last glacial period, resulting in very different landscape features and physiography north and south of the terminal moraine (along which Interstate 80 traversing east-west through northern New Jersey is roughly aligned). Areas to the north of the moraine are more rugged in topography, with massive, discontinuous rock ridges,

steep, narrow valleys, frequent rock outcroppings, and elevations averaging about 300 meters (ca. 1,000 feet) up to 460 meters (1,500 feet) above sea level. The northern section also contains many large, glacially-formed lakes and wetlands and is generally heavily forested; all of these features are of great ecological significance. The southern portion of the Highlands is more gently sloping and less dissected, with more open agricultural lands and early successional vegetation; elevations are as low as 105 meters (350 feet) in the valleys. Where the Hudson River cuts through the Highlands in the vicinity of West Point and Storm King, the physiographic relief is often quite dramatic and ranges from nearly sea level at the base along the river to 425 meters (1,400 feet) in elevation. Soils in the Highlands, especially in the northern, glaciated sections, are generally very shallow, rocky, and strongly acidic. One especially noteworthy feature of the Highlands is the fact that it is an important drainage divide and headwater source for several major river systems in the watershed including the Raritan, Passaic, Wallkill, and Croton Rivers, as well as several rivers draining westward into the Delaware River watershed.

The *Manhattan Prong*, also known as the *Manhattan Hills*, is a landscape of rolling hills and valleys with elevations generally less than 100 meters (330 feet) above sea level, but ranging from sea level to nearly 275 meters (900 feet) above sea level. The highest point in Manhattan, in Fort Tryon Park, is about 80 meters (260 feet). The bedrock of the Manhattan Prong underlies much of southwestern Connecticut, Westchester County, New York, and New York City, and ends at the southern tip of Manhattan Island. The valleys are principally marble and more easily erodible than the schists and gneisses of this unit's higher elevations. The hills are primarily erosion-resistant and tightly folded metamorphic rocks, mostly gneisses and schists with some local deposits of quartzite, overlain with till and coastal plain deposits; they represent the vestiges of ancient, worn-down mountain ranges. Three distinct metamorphic rock formations make up the Manhattan Prong; known collectively as the New York City group, these are: the highly folded and contorted Fordham gneiss, the oldest and most widespread of the formations; the Inwood marble, derived from dolomitic limestone; and the younger Manhattan Formation, consisting largely of mica schist, overlying the Inwood marble and making up most of the rock outcrops on Manhattan Island. The soils are mostly acidic, shallow to deep, and rocky. Rivers of note in this geomorphic unit include the Harlem River, the lower Hudson River, the East River, and the Bronx River. All of these are underlain by Inwood marble except for the Bronx River; it originally flowed through the marble valley, but changed its course to its present flow through mica schist.

Just south of the Manhattan Prong, Staten Island is geologically distinctive and unique in the watershed in that it is partially underlain by serpentine rock, or serpentinite, an altered igneous rock with characteristic physical and chemical properties. The chemical properties of serpentine often exert a profound influence on the flora and vegetation of an area. Few deposits of this material exist elsewhere in the region, making Staten Island's serpentine rocks regionally significant, even though small in total area.

The *Taconic Mountains* section of the New England Province runs in a narrow north-south trending strip along the southeastern border of New York, the southwestern border of Vermont, the western border of Massachusetts, and the northwestern border of Connecticut. To the west, the Taconics are bordered by the Hudson Valley portion of the Great Valley, while their eastern boundary is formed by the Berkshires and by the Hoosac Mountains, which are southern extensions of the Green Mountains of Vermont. The bedrock geology and geological history of this region are extremely complex and diverse, with intensely folded and faulted metamorphic

shales, slates, phyllites, quartzite, schists, gneisses, and graywacke (sandstone/conglomerate) predominating in the uplands, and belts of carbonates, limestone, and marble forming the valleys. Much of this area's geological complexity is the result of a collision between an ancient volcanic island arc and the continent of proto-North America; this collision pushed rocks from western Massachusetts into New York around 450 million years ago, bending and upthrusting rocks which had lain flat. The uptilted edges of these different layers have been differentially worn away according to their rock type; softer rocks (carbonates, e.g., limestones and marbles) are worn away to form the valleys, while the more erosion-resistant harder rocks form the hills. This gives the Taconics its characteristic topography of sharp ridges and narrow valleys.

Elevations along the more low-lying western edge of this geomorphic section, adjacent to the Hudson Valley, begin at about 120 meters (400 feet) above sea level and increase in elevation up to around 610 meters (2,000 feet) along the Massachusetts state line, averaging around 550 to 610 meters (1,800 to 2,000 feet); maximum elevation in Massachusetts is close to 850 meters (2,800 feet). Elevations also generally decrease toward the south, a reflection of the harder quartzites and gneisses in the north and predominance of softer shales, slates, and limestones in the southern portions. While the higher peaks of the Taconic Mountains lie eastward and outside of the New York Bight watershed, their western slopes or foothills extend into the eastern New York section of the watershed along its border with western New England. These western foothills of the Taconic Mountains are sometimes referred to as the *Taconic Highlands*. Their north-south oriented landscape is relatively steep and hilly near their easternmost edge, adjacent to the Taconic Mountains in the states of Vermont, Massachusetts, and Connecticut, and becomes progressively more gently rolling westward, towards the Hudson River valley. In the southern portion of these foothills, where the elevations are lowest, the landscape is largely that of a broad, gently undulating valley. There are considerable open, nonforested lands with extensive agriculture over much of this region. Soils on the uplands are relatively acid, coarse-textured, and often shallow, while valleys are more fertile and basic and contain extensive vegetated wetland complexes. Carbonate outcrops are common in the valleys.

Two areas within the Taconic section are especially distinctive: the Rensselaer Plateau and Stissing Mountain. The *Rensselaer Plateau* or *Rensselaer Hills*, underlain with Cambrian quartzites and graywacke, is a nonmountainous area of the Taconics located about 16 kilometers (10 miles) east of Albany in the northeastern corner of the New York Bight watershed study area. It projects prominently above the Hudson Valley and the surrounding foothills of the Taconics to the west, north, and south, and above the valley of the Little Hoosic River, which separates the plateau from the higher ridges of the Taconic Mountain range to the east. This hilly plateau is about 32 kilometers (20 miles) long and 14 kilometers (9 miles) wide, with surface elevations generally ranging from 457 to 610 meters (1,500 to 2,000 feet) high. Its surface topography is rolling, with broad swells and long slopes, and contains many swamps and lakes. Most of the land is wooded, with little active agriculture owing to the thin, stony soils covered by glacial boulders.

*Stissing Mountain* (428 meters [1,403 feet]), located in Dutchess County, New York, about 16 kilometers (10 miles) west of the Connecticut-New York border near Lakeville, Connecticut, rises abruptly nearly 305 meters (1,000 feet) above the surrounding lowlands. In contrast to the slate hills to the west and carbonate lowlands and wetlands to the east that surround it, the nearly 8-kilometer (5-mile) long Stissing Mountain is composed of hard, erosion-resistant and acidic Precambrian gneisses overlain in many places by Lower Cambrian quartzites. The gneisses themselves overlie, or float on, much younger rocks, probably the result of thrust faulting, also

common elsewhere in the Taconic section. The east side of Stissing Mountain is the steepest, with slopes averaging 40 percent. Its slopes and crests are heavily forested, with scattered rock outcrops, vertical ledges, and very rocky, shallow, acidic soils formed from glacial till derived from gneiss; substantial accumulations of talus at the foot of the mountain consist of large blocks of gneiss.

#### **4. Ridge and Valley Province**

Great Valley (Kittatinny, Wallkill, and Hudson Valleys)

Shawangunk - Kittatinny Ridge

The Ridge and Valley Province of the New York Bight watershed is part of a much larger geological province that extends from Canada to the southern United States as a narrow belt of sinuous ridges and interconnecting valleys with a general northeast-southwest orientation. The lowland valley section of this province is generally referred to as the *Great Valley*. Within the New York Bight watershed, the *Great Valley* section is collectively composed of the *Kittatinny*, *Wallkill* and *Hudson Valleys*. This section consists of a long and continuous valley system that curves gently northeastward through northwestern New Jersey from the Delaware River through the *Kittatinny Valley* of New Jersey and the *Wallkill Valley* of New Jersey and New York to the confluence of the Hudson River, and then continues northwards up the *Hudson Valley* to the Champlain Valley, beyond the New York Bight watershed boundary. These valleys are broad and gently rolling and surrounded, from south to north, by the Kittatinny, Shawangunk, Catskill, and Helderberg Mountains on the west and northwest, by the Taconic Mountains to the east, and by the New York - New Jersey Highlands to the southeast. The valleys themselves were created largely by the actions of groundwater and surface water slowly dissolving and eroding the carbonate bedrocks (sedimentary shales and limestones) that underlie much of the region. Because of the rich soils and flatness of the terrain, coupled with a relatively mild climate, much of the valley region is in agriculture, with localized centers of industry and residential development; there are also sizable areas of forests and wetlands.

The northern *Kittatinny Valley* and the *Wallkill Valley* lie within the watershed boundaries of the New York Bight and are drained by the northeast-flowing Wallkill River and its tributaries from their origin in northwestern New Jersey up to the Wallkill's confluence with Rondout Creek close to where the Rondout flows into the Hudson River. This section of the Great Valley averages 16 to 25 kilometers (10 to 15 miles) in width and has a broad, flat to undulating contour varying in elevation from about 120 to 300 meters (400 to 1,000 feet) above sea level, with most of the land lying below 150 meters (500 feet). The valleys are mostly underlain with limestones, dolomites, and shales, and largely covered with glacial till. The valley soils are deep, fertile, and relatively well-drained, except for restricted areas of peats and mucks, which are the sites of former shallow glacial lakes. The southern Kittatinny Valley southwest of and contiguous with the Wallkill Valley is drained by the Paulins Kill southwestward to the Delaware River and is, therefore, outside of the New York Bight watershed. At the Delaware River, the Great Valley system continues to the southwest into Pennsylvania.

Included in the valley section of the Ridge and Valley Province is the long narrow valley that lies between the Shawangunk - Kittatinny ridgeline and Allegheny Plateau. In the New York State section of this valley, west of the Shawangunks, the valley is continuous from Pennsylvania, near Port Jervis, New York, northeastward to the Hudson River. The valley is known to geologists as the *Port Jervis Trough*, but locally by the names of rivers and creeks that run through it. To the west and north of the Shawangunk ridgeline, this valley is drained by the

northeastward-flowing Rondout Creek, which joins the Wallkill River just east of Rosendale, New York and then continues east a short distance to join the Hudson River near Kingston, New York. In this same narrow valley west of the Shawangunk ridgeline, but south of and in headwater opposition to Rondout Creek, the Basher Kill and Neversink River flow southwestward to drain into the Delaware River; this section of the valley is not a part of the New York Bight watershed. Similarly, the valley of the Delaware River (Minisink Valley) and other small tributary valleys west of the Kittatinny ridgeline in New Jersey, though a part of the Ridge and Valley Province in the state, lie outside the New York Bight watershed and are therefore not included in this report.

Within the north-central section of the New York Bight watershed project area, the *Hudson Valley* forms a narrow corridor of rolling plains and hills, averaging around 16 kilometers (10 miles) across in width in an east-west direction, from the vicinity of Troy downriver to Newburgh. The Hudson River is very much a dominant landscape feature in this section of the Ridge and Valley Province. Interlaced among the hills and plains of the valley are long, narrow, stream bottomlands and wetlands. The valley is composed primarily of sedimentary shales, siltstones, sandstones, and limestones; most of the soils derived from these materials are medium-textured and acid to slightly acid in pH. Closer to the river, the soils are mostly medium-textured to fine-textured glacial lake or marine sediments; in the Albany area there are coarse sandy and gravelly soils derived from a large delta built along the west shores of Glacial Lake Albany, whose waters filled most of the valley some 15,000 years ago. Elevations range from near sea level at the southern end of this valley to 60 meters (200 feet) high, with some maximum local elevations of just under 150 meters (500 feet). In a few areas below Kingston there are a number of hills, not typical of the rest of this region, that approach or exceed 300 meters (ca. 1,000 feet) in elevation.

The *Shawangunk - Kittatinny Mountain ridgeline* is the northernmost ridge in the Ridge and Valley Province and the only prominent ridgeline of this province in the watershed except for the much smaller *Schunnemunk Mountain* situated along the eastern edge of the valley adjacent to the Highlands. Beyond the watershed to the southwest, the Kittatinny Ridge continues to the Delaware River where it is cut by the Delaware Water Gap. West of the Delaware River the Kittatinny Mountain ridge continues southwestward into Pennsylvania to Wind Gap, Pennsylvania, where the ridge continues south and southwestward as Blue Mountain. The Shawangunk - Kittatinny Ridge is nearly 160 kilometers (100 miles) long, stretching northeastward from the Delaware River in northwestern New Jersey to its northeastern terminus approximately 16 kilometers (10 miles) southwest of Kingston, New York. It is composed of sharply-folded sedimentary rocks, mostly shale, capped with erosion-resistant sandstones and quartz conglomerates, with increasing amounts of limestone on the western slopes along the Delaware River. As a result of these different bedrocks and their dip, steep cliffs are prominent along the east slope of the ridge while gentle slopes prevail on the western side. The overall shape of the ridge is that of a long, narrow, pointed dumbbell, with the center section being the narrowest (less than 2 kilometers [1.25 miles] wide) and areas near the two ends widening out to more than 10 kilometers (6 miles) in width. Elevations at the base start at about 120 meters (400 feet) above sea level; along the ridgetop elevations average well over 300 meters (1,000 feet). The highest elevation in the Kittatinny section of the ridge is 550 meters (1,803 feet), at High Point, New Jersey; in the Shawangunk section, highest elevation is 698 meters (2,289 feet) at Lake Maratanza, New York. Glaciated northern sections of the ridge contain several rock basin lakes scoured out by the ice sheet, such as Sunfish Pond, Lake Marcia, and Mohonk and

Minnewaska Lakes. Most of the land area is in forest, rocky outcrops, and bare escarpments.

## **5. Appalachian Plateaus Province**

Glaciated Allegheny Plateau

Catskill Mountains

Helderberg Mountains

The Appalachian Plateaus Province is a broad belt of flat-lying and relatively unfolded layers of sedimentary rock, sandstones, shales, limestones, and conglomerates, that extends from northern New York State, from just north of the Catskill Mountains west to the vicinity of Cleveland, Ohio; from there it extends southward through Ohio, Kentucky, and Tennessee to northwestern Alabama, where it meets the Coastal Plain. Several geomorphic sections have been identified and delineated over this Province, including the Allegheny Mountains, Catskill Mountains, Cumberland Mountains, and Cumberland Plateau. Along its edges, the Appalachian Plateaus Province is bounded by outfacing escarpments or dissected mountain fronts, which impart an almost mountainous topography to the region, especially along the eastern margin of the province. The Catskill Mountains are a prominent example of this mountainous appearance, owing to the strong physiographic relief in those areas adjacent to the low-lying Hudson and Kittatinny Valleys.

The *Glaciated Allegheny Plateau* in the New York Bight watershed represents the northeasternmost part of the Appalachian Plateaus Province. It is a maturely dissected plateau that has been extensively modified by Pleistocene glaciations, particularly the late Wisconsin glaciation. Within the Bight watershed it is a mostly high and rugged plateau region formed of uplifted marine sandstones and shales, and is characterized by flat-topped hills and deeply dissected valleys. This region forms the northwestern border of the New York Bight watershed study area.

The *Catskill Mountains* or *Catskills*, as they are commonly known, are situated along the western edge of the Hudson Valley west of Kingston and Catskill, New York, and contain the highest peaks in the New York Bight study watershed. The highest topography in the Appalachian Plateaus Province, the Catskills are not technically mountains at all, but an eroded, topographically dissected plateau that has been carved by stream erosion into sharp-crested divides. Such areas as the Catskills and Poconos are called mountains largely because of the shape of their landforms rather than on the basis of their origin, and the name persists. Indeed, this impression of mountains is especially reinforced along the eastern edge of the Catskills where the plateau escarpment stands 915 meters (3,000 feet) above the Hudson Valley floor to the east. Especially noteworthy is the fact that the highest peaks of the Catskills, constituting an area approximately 64 kilometers (40 miles) in diameter, are all at about the same elevation, with 34 peaks over 1,067 meters (3,500 feet). Geomorphologists have different theories about this. Some think it is the result of regional uplifting and erosion of a former plain; others think that, because the high peaks of the Catskills are all formed of the same erosion-resistant sandstones, they have worn down at the same rate and therefore continue to have very similar heights. Elevations at the eastern base of the Catskills adjacent to the Hudson Valley start at around 175 meters (500 feet) and increase rapidly to where local elevations over much of the area average well over 610 meters (2,000 feet); indeed, many of the higher peaks are over 915 meters (3,000 feet) above sea level. The maximum elevation in the Catskills is 1,274 meters (4,180 feet), at the top of Slide Mountain, the highest point in the New York Bight study area. The topography of this section is extremely rugged, dominated by high peaks, steep ridges, and deep ravines, and

containing few streams and valleys, perhaps due to the extreme permeability of the sandstones. On the peaks themselves glacial till deposits and soils are quite thin and there is a fair amount of exposed bedrock, in contrast to the valleys which contain thick glacial deposits and rock debris. Several headwater streams drain the high peaks of the Catskills and flow into three major drainage systems: the Delaware, Hudson, and Mohawk Rivers. Within the New York Bight, or Hudson River, watershed portion of these mountains, the major tributary is Esopus Creek, which essentially divides the Catskills into two distinct clusters of high peaks. Other rivers of note within the watershed include Kaaterskill Creek, Plattekill Creek, and Rondout Creek. The major rivers of the other drainage systems are the Neversink and Delaware Rivers, which drain into the Delaware River watershed, and Schoharie Creek, which drains into the Mohawk River which, in turn, drains into the Hudson River system north of Troy, north of the study area.

The *Helderberg Mountains* comprise a relatively restricted section of the Appalachian Plateau and form the northeastern border of the Glaciated Allegheny Plateau. Like the Catskills, the Helderbergs represent an eroded and dissected portion of the Allegheny Plateau and are not true mountains. Because the principal limestones (Helderberg group) that make up these mountains are more erosion-resistant than the layers below and above them, the eastern and northeastern faces of the Helderberg Mountains form a very steep and pronounced escarpment, or cliff face, and contain numerous caves. It is this cliff face, the *Helderberg Escarpment*, that gives the area its topographic prominence and regional significance. The Helderberg region as a whole is characterized by a plateau-like appearance, with flat hilltops intermixed with steep, shallow-soil valleys and elevations that range from 274 to 488 meters (900 to 1,600 feet) above sea level. Elevations at the base of the eastern and northeastern faces of the Helderberg Escarpment range from about 150 to 245 meters (500 to 800 feet), with average elevations along the top ranging from 305 to 365 meters (1,000 to 1,200 feet). The highest elevation in the Helderbergs within the watershed study area is 555 meters (1,822 feet); to the west, outside the watershed, the highest peak in the Helderbergs stands at 668 meters (2,191 feet). The mountains are heavily forested, though elsewhere in this geomorphic section and in the adjacent Hudson and Mohawk Valleys, a much larger percentage of the area is in open fields and shrublands.

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- Figure 3